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REPLACEMENT OF SR 4990 BY BARIUM STYPHNATE IN THE MK 24 ACTUATOR

By
Stephen C. Urman

12 AUGUST 1970

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND 20910

NOLTR 70-98

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ABSTRACT: DuPont SR 4990, a single-base propellant used in Navy explosive actuators, is no longer produced. This necessitated a search for an adequate replacement for the SR 4990 in the Mk 24 Actuator. Experimental work was performed with barium styphnate, lead mononitroresorcinate, and two DuPont manufactured powders. Candidate materials were first screened using a pressure bomb. Final testing was performed in the Mk 24 Actuator design. Test results showed that of the four candidates, barium styphnate is the best material for the Actuator Mk 24.

PUBLISHED 12 AUGUST 1970

Explosions Research Department
U.S. Naval Ordnance Laboratory
White Oak, Silver Spring, Maryland

REPLACEMENT OF SR 4990 BY BARIUM STYPHNATE IN THE MK 24 ACTUATOR

This study was undertaken to determine a replacement for SR 4990 in the Mk 24 Actuator. The work was performed under Task ORD 053 470/092-1/U38 01 and NOL 412/ORD 053 Prob. B01.

The results should be of interest to persons engaged in actuator design and propellant research.

The identification of commercial materials implies no criticisms or endorsement of these products by the U. S. Naval Ordnance Laboratory.

GEORGE G. BALL
Captain, USN
Commander

C. J. ARONSON
By direction

CONTENTS

Figures (continued)

INTRODUCTION

1. The Mk 24 Mod 0 Actuator, used in the Mk 20 Cable Cutter, contains SR-4990 as the propellant base charge. SR-4990 is a single base smokeless powder manufactured by DuPont and has been used as the propellant material in Navy actuators because it produces a very desirable rapid pressure rise. However, DuPont has ceased production of SR-4990, making it necessary for the Navy to find a suitable replacement material for use in the Mk 24 Mod 0 Actuator.

2. Besides a rapid pressure rise, the replacement material should have: (a) high pressure output, (b) good loading properties, (c) safe handling properties, (d) storage stability, and (e) bulk density sufficiently high to assure that an adequate quantity of base charge can be loaded within the present volume of the actuator. In addition to possessing these qualities, it is desirable that the replacement be non-proprietary and covered by a military specification.

3. Various available materials were considered as possible replacements for SR-4990. Two proprietary samples supplied by DuPont and said to have pressure-time responses similar to that of SR-4990, were included in initial testing in case non-proprietary substitutes were not successful. They were SR-8044 and "Hi-Skor" 700-x (DuPont Powders). Lead mononitroresorcinate is used in various dimple and bellows motors and was thought to have possible application. A literature search revealed that barium styphnate had a pressure-time response which suggested its possible applicability.

4. The experimental work was divided into two phases. A basic survey was first made of the possible substitutes by testing in a pressure bomb to determine how closely the substitute materials matched the pressure-time curves produced by SR-4990. Materials found satisfactory in the pressure bomb test were then tested in the Mk 24 Actuator.

EXPERIMENTAL APPARATUS

5. A small pressure bomb was used to compare the pressure time profiles of the test materials with that of SR-4990. This pressure bomb, Fig. 1, has been successfully used by E. E. Kilmer[1] to evaluate different propellant materials for actuators.

6. A Norwood strain gage pressure transducer, with a range up to 10,000 psi, was used in conjunction with a Model 5AC Pressure Monitor. The pressure monitor provides a source of power and completes the bridge and calibrating circuits. This arrangement was monitored by a Tektronix oscilloscope, Model 545, and the resultant curves were recorded by a Polaroid Land camera. A block diagram of the experimental arrangement is shown in Fig. 2.

7. The Norwood bonded strain gage pressure transducer has proved itself in static and dynamic pressure measurements over the years. The gage's catenary diaphragm is designed to minimize temperature effects and volume changes. An increased pressure on the diaphragm produces a minute dimensional change in the strain tube. This change is reflected by an equivalent resistance change in the strain gages bonded to the tube. Past experience with propellant powders has shown this transducer to be unaffected by corrosive gases, that it has the desired electrical characteristics, and it facilitates the cleaning of the pressure bomb.

8. For convenience of testing, the Mk 15 Actuator, Fig. 3, was used as the test vehicle to compare the different candidate powders. The Mk 15 Actuator has 25 mg of propellant base charge compared with 1 gram of propellant base charge in the Mk 24 Actuator. Thus, the pressure generated from the Mk 15 Actuator is much less than that of the Mk 24 Actuator and therefore more adaptable to the pressure bomb arrangement described above. In addition, smaller amounts of substitute material can be used for testing purposes. Also, the Mk 15 Actuator is relatively simple in design and easier to fabricate than the Mk 24 Actuator.

EXPERIMENTAL RESULTS

Pressure-Bomb Work

9. Initial exploratory experiments were performed using the Mk 15 Actuator with 25 mg of SR-4990. A typical response is shown in Fig. 4. A peak pressure of approximately 1900 psi is generated in the pressure bomb in 2-3 milliseconds. To isolate the pressure-time effect of SR-4990 from the ignition charge of lead styphnate, various charge weights of lead styphnate were tried. See Fig. 5. When these results are compared with the normal Mk 15 profile, (Fig. 4), a marked difference in the pressure build up was noticed. This effect of pressure on burning rate demonstrated that the 25 mg tests might not scale too well with larger amounts of material in the final Mk 24 Actuator design. Actuators with 15 mg of lead styphnate gave the closest duplication of the pressure-time response of the normal Mk 15. It was concluded that a five milligram charge of lead styphnate would be sufficient to isolate the response of the propellant. To ensure adequate ignition of the propellant, five milligrams of FA 878 Igniter Mix* were pressed at the same loading pressure as the lead styphnate in the charge holder on top of the increment of lead styphnate. This igniter mix is used to ignite the propellant charge in the Mk 24 Actuator and is very effective when used in this operation. As shown in Fig. 6, the response of these actuators was as good as the original design containing 20 mg of lead styphnate.

10. "Hi-SKOR" 700-x and SR-8044. These are two Dupont powders which were recommended by DuPont as possible substitutes for SR-4990. The same weight (25 mg) as SR-4990 was employed. Figure 7 shows these powders to be promising, giving pressures in the 1500-2000 psi range within 2-4 milliseconds. It was decided to keep them in reserve for further study if necessary in case the non-proprietary materials were not satisfactory.

* 40% zirconium, 20% barium nitrate, 20% lead peroxide, and 20% PETN.

11 Barium Styphnate (Barium Trinitroresorcinate). Twenty-five mg of barium styphnate, loaded loose (the same conditions as SR-4990) resulted in a low pressure and extremely quick response time. See Fig. 8a. (The charge holder in this test was not filled completely due to the higher density of barium styphnate compared with SR-4990.) Filling the charge holder (55 mg) with loose barium styphnate increased the pressure correspondingly, and the fast rise time was maintained. See Fig. 8b. To determine whether we could achieve a slower burning rate with a suitable peak pressure, tests were run with actuators containing ninety mg barium styphnate but pressed in the charge holders at different loading pressures. Figure 9 shows typical oscillograms illustrating the results obtained at 5000 psi, 10,000 psi, and 15,000 psi. The charge holder was filled completely at 5000 psi loading pressure. The pressure rise times and magnitude of the peak pressures for the various loading methods are summarized in Table I. Figure 10 shows the P-T profiles of actuators loaded with barium styphnate compared with those loaded with SR-4990. By using 5000 psi as the loading pressure, the desired response could be produced in the same volume as SR-4990.

12. Lead Mononitroresorcinate. Lead Mononitroresorcinate (LMNR) when used by itself generated a pressure which was too low. Its rate of burning was also too low. See Fig. 11. This is due to the "oxygen deficiency" of LMNR. The oxygen balance is calculated from the empirical formula of a compound in percentage of oxygen required for complete conversion of carbon to CO_2 and hydrogen to water. For LMNR, it was determined to be -48% to CO_2 and -15% to CO. However, when used with an oxidizer added for complete combustion, the pressure build up can be enhanced. The oxidizer used here was $KClO_4$ and the different ratios by weight tried were 85% LMNR - 15% $KClO_4$, 80% LMNR - 20% $KClO_4$, 75% LMNR - 25% $KClO_4$, and 60% LMNR - 40% $KClO_4$. See Fig. 12. The actuators loaded with a 75/25% mixture pressed at 5000 psi gave pressure-time profiles most similar to those of actuators with SR-4990. The different responses from varying loading conditions and mixtures are summarized in Table II. In Fig. 13, the P-T profile of LMNR-$KClO_4$ (75/25%) as obtained from the pressure bomb is plotted and compared with SR-4990.

Mk 24 Actuator Work

13. The next phase of the program consisted of replacing the base charge in the Mk 24 Actuator with barium styphnate and LMNR/$KClO_4$ (75/25%) and comparing their performance with the standard Mk 24 Actuator. Work on the proprietary powders was discontinued at this time pending the results of the subsequent experimentation. The Mk 24 Actuator, Fig. 14, is a hermetically sealed, stab initiated device which contains 135 mg of NOL 130 primer mix, 150 mg of FA 878 igniter mix, and one gram of SR-4990 as the base charge.

14. The SR-4990 explosive load was replaced with 4.4 grams of barium styphnate pressed at 5000 psi and 5.6 grams of LMNR/$KClO_4$ at 5000 psi. During the fabrication of the actuators with LMNR/$KClO_4$, difficulty was encountered during the soldering process. When heat was applied to melt the solder, a few actuators accidentally ignited during the process. No accidental ignitions were obtained when the barium styphnate loaded actuators were sealed.

15. The actuators loaded with the two candidates were tested for output using the Mk 24 Actuator output fixture. In this device, the actuator drives a piston which is required to shear a 0.172-in. steel rod. All of the samples tested (10 each) passed the test at room temperature and at -65°F. In fact, rods up to 0.218-in. diameter could be successfully sheared at room temperature. (The upper bound on the output from SR-4990 loaded Mk 24 Actuators is 0.197 in.) Actuators with the two candidates were tried in the Mk 20 cable cutter and successfully sheared the 1-in. diameter cable.

16. The actuators were then subjected to rough handling and surveillance tests. (See Table III.) Two out of fifteen actuators with LMNR/$KClO_4$ fired on impact in the 40-ft. guided drop test. This is not too uncommon for stab initiated items, as they occasionally will fire on this test. All actuators with barium styphnate successfully passed the safety tests. The samples remaining from the safety tests were tested in an output fixture by the impact of a two-ounce steel ball from four inches on a standard firing pin. The 0.172-in. diameter steel drill rod was sheared successfully each time by actuators containing barium styphnate. One out of fifteen actuators loaded with LMNR/$KClO_4$ failed to shear the rod after being subjected to the 40-ft. guided drop test. One out of fifteen failed after being stored at 160°F and two out of fifteen failed after a sequential transportation, high frequency vibration test. The reasons for the failures are not known. As a result of these tests, barium styphnate was judged to be more consistent and reliable than lead mononitroresorcinate when used in the Mk 24 Actuator.

DISCUSSION

17. The results of impact sensitivity tests of the candidate materials are shown in Table IV. Although both candidates are more impact sensitive than SR-4990, barium styphnate is considerably less impact sensitive than LMNR/$KClO_4$. Although barium styphnate is regarded as a primary explosive, it is safer to manufacture and use than most other primaries.[2] It is also relatively unsusceptible to accidental ignition from electrostatic sources.[2]

18. A cost analysis revealed no significant difference between the current price of LMNR (price of $KClO_4$ can be neglected when compared with LMNR) and barium styphnate. However, the extra step of mixing LMNR and $KClO_4$ must be considered. Efforts have to be made to insure uniform blending of the two ingredients. Otherwise, inconsistent burning times with varying pressure outputs will result. To facilitate the blending, it is necessary to use potassium perchlorate crystals which are of very small size. Also, because of the sensitivity of these materials, adequate safety precautions must be taken during the mixing process. See Fig. 15 for a photomicrograph of a LMNR/$KClO_4$ mixture.

19. The difficulty of soldering actuators with LMNR/$KClO_4$ was previously mentioned. The soldering is done with the use of a high frequency induction heater equipped with a reset timing device. The amount of heat delivered and its duration can be varied depending on the particular item to be soldered. The settings are very crucial to insure proper melting of the solder without any accidents. Hence, extra time and efforts were necessary to solder a complete batch of actuators with LMNR/$KClO_4$. Due to the small difference between the melting point of the solder and the ignition temperature of LMNR/$KClO_4$, a lower melting point solder (tin-indium) would have to be used. If not successful, an alternate method for hermetically sealing the actuator would have to be found. There were no difficulties encountered in soldering actuators loaded with barium styphnate.

20. Barium styphnate, has been found to be relatively stable to heating and to storage in vacuum and humid conditions.[2] It is also compatible with the metals and other materials likely to be in contact with it in explosive stores. A photomicrograph of barium styphnate is provided in Fig. 16. The particle size ranges from 10 to 500 microns. As is shown in the pressure-time profiles in Fig. 9, it is possible, by varying the loading pressure of barium styphnate in the actuator, to closely approximate the burning response of SR-4990.

CONCLUSIONS

21. Two possible non-proprietary candidates for replacement of SR-4990 have been found. Work with the Mk 24 Actuator has shown barium styphnate to be more reliable than a lead mononitroresorcinate/$KClO_4$ mixture. Superior chemical and physical properties have also demonstrated the advantage of using barium styphnate over the LMNR/$KClO_4$ mixture.

22. Barium styphnate is recommended as the substitute for SR-4990 in the Mk 24 Actuator.

REFERENCES

1. Kilmer, E. E., "The Actuator, Explosive WOX-23A, An Actuator to Replace Actuator Mk 3 Mod 0 in the Explosive Switch Mk 46 Mod 0", NAVORD Rept. 6761, May 1960.

2. Taylor, G. W. C., Thomas, A. T., and Holloway, K. J., "The Manufacture of Barium Styphnate RD 1340" (U), Ministry of Supply, Explosive Research and Development Establishment, Rept. No. 28/R/55, Feb. 1956, conf.

TABLE 1 PRESSURE-TIME RESPONSES OF BARIUM STYPHNATE

POWDER WEIGHT	LOADING PRESSURE (psi)	PRESSURE RISE TIME (MILLISEC)	PEAK PRESSURE (psi)
25 mg	0	0.4	1,050
55 mg	0	0.6	1,760
90 mg	5,000	2.0	2,100
90 mg	10,000	2.0	2,100
90 mg	15,000	2.0	2,400

TABLE 2 PRESSURE-TIME RESPONSES OF LMNR AND LMNR/$KClO_4$

POWDER	POWDER WEIGHT	LOADING PRESSURE (psi)	PRESSURE RISE TIME (MILLISEC)	PEAK PRESSURE (psi)
LMNR	15 mg	0	—	250
LMNR	120 mg	10,000	5.0	560
LMNR	180 mg	5,000	6.0	875
LMNR-$KClO_4$ (85/15)	180 mg	5,000	6.0	2,020
LMNR-$KClO_4$ (80/20)	180 mg	5,000	3.0	1,750
LMNR-$KClO_4$ (75/25)	180 mg	5,000	2.0	2,020
LMNR-$KClO_4$ (60/40)	180 mg	5000	—	1900

TABLE 3 ROUGH HANDLING/SURVEILLANCE TEST RESULTS

	ACTION DURING TEST		OUTPUT RESULTS	
	$LMNR/KClO_4$	BARIUM STYPHNATE	$LMNR/KClO_4$	BARIUM STYPHNATE
T&H CYCLING (TEST 105)	——	——	√	√
JOLT (TEST 101)	NO FIRES	NO FIRES	√	√
JUMBLE (TEST 102)	NO FIRES	NO FIRES	√	√
40' GUIDED DROP	2/15*	NO FIRES	O 1/15	√
160° F STORAGE (28 DAYS)	——	——	O 1/15	√
→ TRANSPORTATION HIGH FREQ VIB TEST 104 II	NO FIRES	NO FIRES	O 2/15	√

√ = PASS

O = FAIL

* = ACCIDENTAL IGNITION

NOTE: TEST NUMBERS REFER TO MIL-STD-331

TABLE 4 IMPACT SENSITIVITY TESTS

SAMPLE	50% HEIGHT (CM)	STANDARD DEVIATION (LOG UNITS)
BARIUM STYPHNATE (BARETOOLS)	19	0.07
BARIUM STYPHNATE (SANDPAPER)	19	0.03
LMNR/$KClO_4$ 75%/25% (BARETOOLS)	7	0.06
LMNR/$KClO_4$ 75%/25% (SANDPAPER)	12	0.10
SR 4990 (BARETOOLS)	37	0.19
SR 4990 (SANDPAPER)	45	0.06

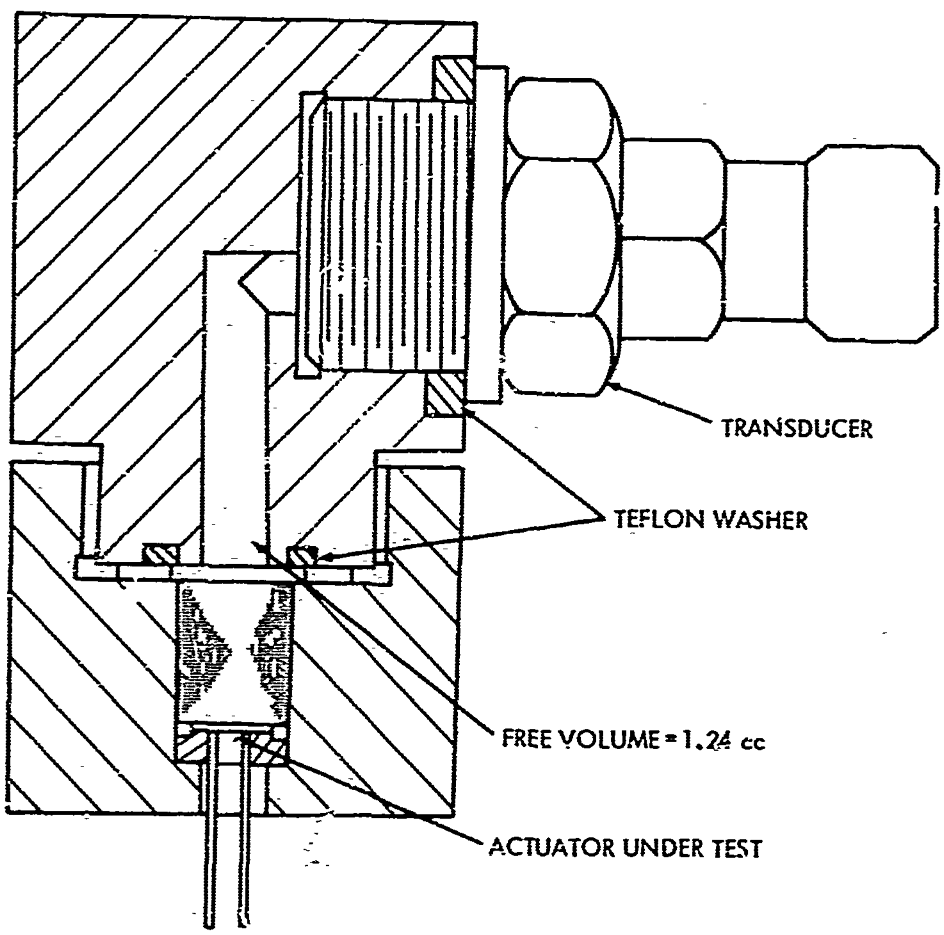


FIG. 1 ASSEMBLY FOR PRESSURE BOMB TESTING

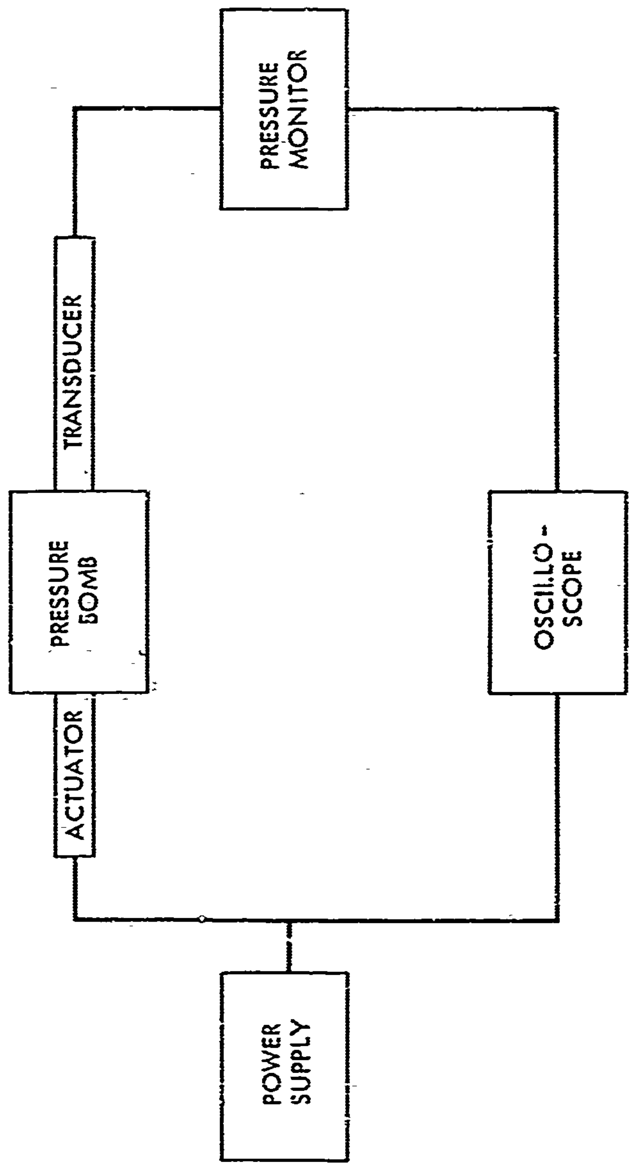


FIG. 2 TEST ARRANGEMENT

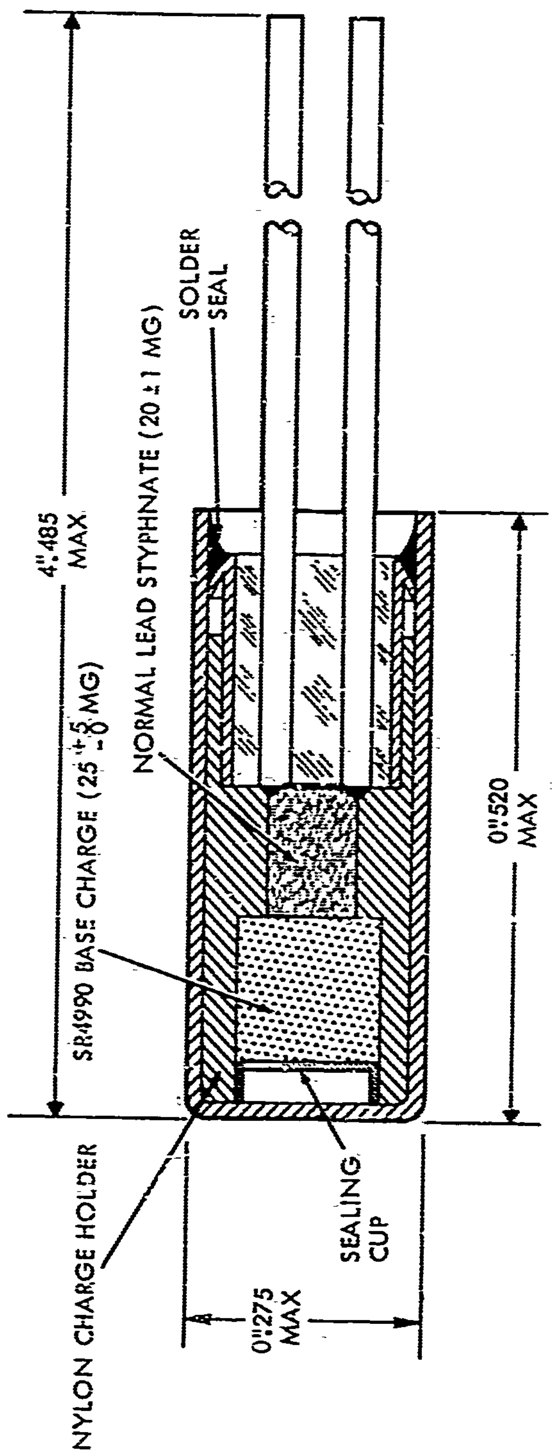
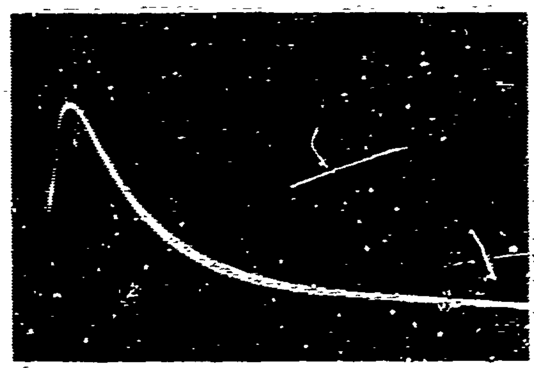


FIG. 3 MK 15 ACTUATOR

PRESSURE

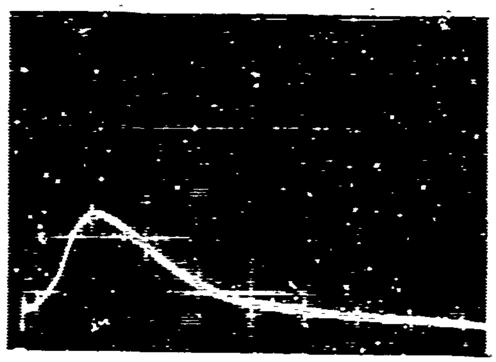


VERT SENS
476 psi/DIV
SWEEP TIME
5 ms/DIV

TIME ⟶

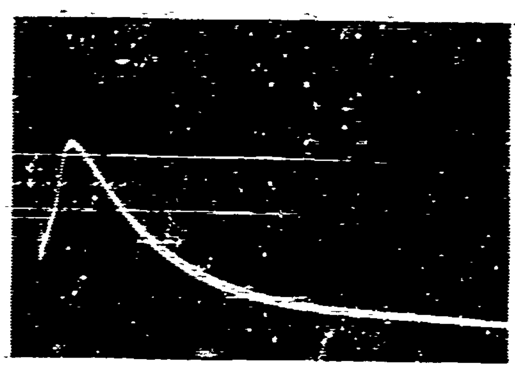
FIG. 4 PRESSURE-TIME PROFILE OF THE MK 15 ACTUATOR

25 mg BASE CHARGE
5 mg NORMAL LEAD
STYPHNATE



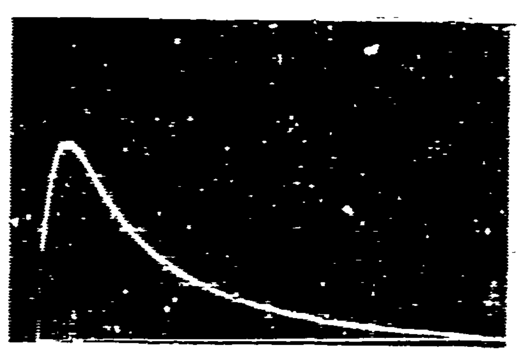
VERT SENS
476 psi/DIV
SWEEP SPEED
5 ms/DIV

25 mg BASE CHARGE
10 mg NORMAL LEAD
STYPHNATE



VERT SENS
476 psi/DIV
SWEEP SPEED
5 ms/DIV

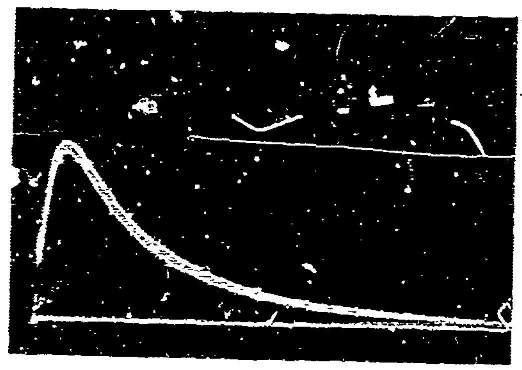
25 mg BASE CHARGE
15 mg NORMAL LEAD
STYPHNATE



VERT SENS
476 psi/DIV
SWEEP SPEED
5 ms/DIV

FIG. 5 PRESSURE-TIME PROFILES OF MK 15 ACTUATORS WITH REDUCED CHARGE OF NORMAL LEAD STYPHNATE

25 mg BASE CHARGE
5 mg NORMAL LEAD STYPHNATE
5 mg FA 878 MIX

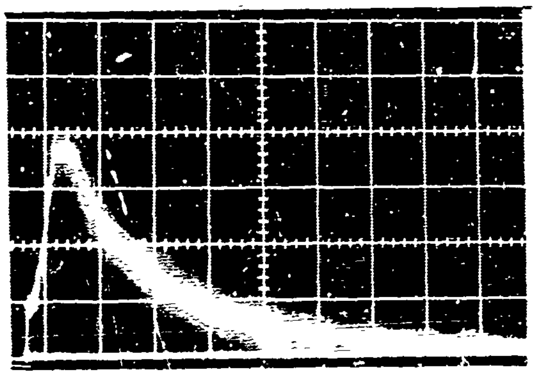


VERTICAL SENSITIVITY: 485 psi/DIV

SWEEP SPEED: 5 MSEC/DIV

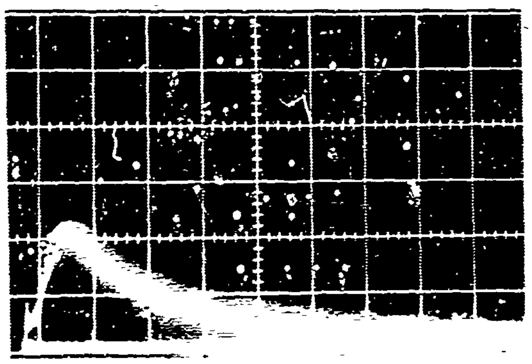
FIG. 6 PRESSURE-TIME PROFILE OF MK 15 ACTUATOR WITH REDUCED IGNITION CHARGE

25 mg SR 8044
5 mg NORMAL LEAD
STYPHNATE
5 mg FA 878
(a)



VERT SENS:
398 psi/DIV
SWEEP SPEED
5 MSEC/DIV

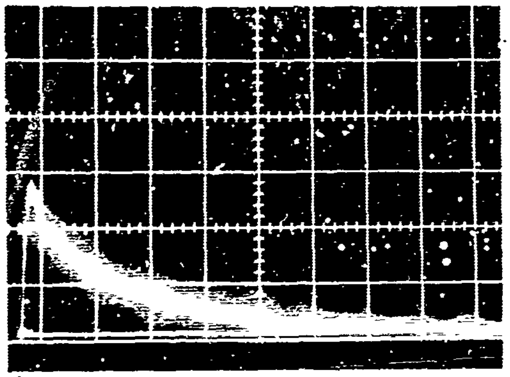
25 mg "HI-SKOR"-700X
5 mg NORMAL LEAD
STYPHNATE
5 mg FA 878
(b)



VERT. SENS:
1000psi/DIV
SWEEP SPEED
5 MSEC/DIV

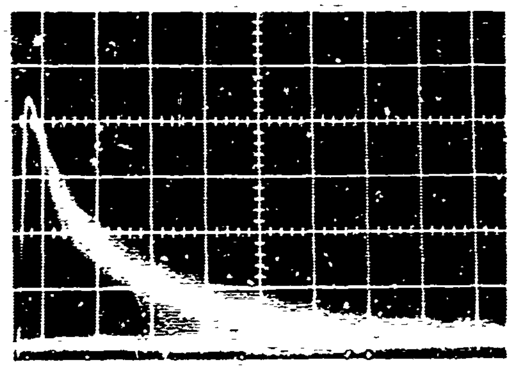
FIG. 7 PRESSURE-TIME RESPONSES OF DUPONT POWDERS

25 mg BARIUM
STYPHNATE
5 mg NORMAL
LEAD STYPHNATE
5 mg FA 878 MIX
(a)



VERT SENS:
375psi/DIV
SWEEP SPEED
5 MSEC/DIV

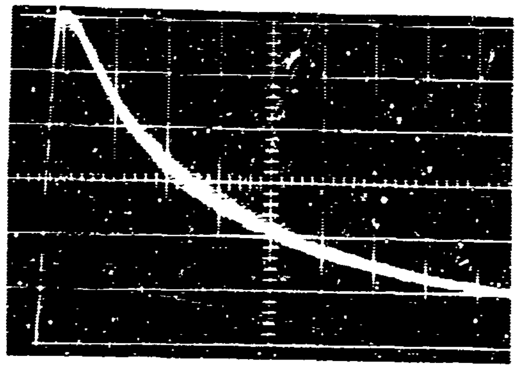
55 mg BARIUM
STYPHNATE
5 mg NORMAL
LEAD STYPHNATE
5 mg FA 878 MIX
(b)



VERT SENS:
400psi/DIV
SWEEP SPEED
5 MSEC/DIV

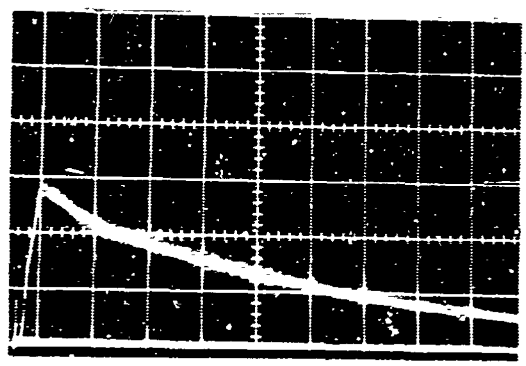
FIG. 8 PRESSURE-TIME RESPONSES OF BARIUM STYPHNATE

90 mg BARIUM
STYPHNATE
LOADING PRESSURE:
5,000 psi



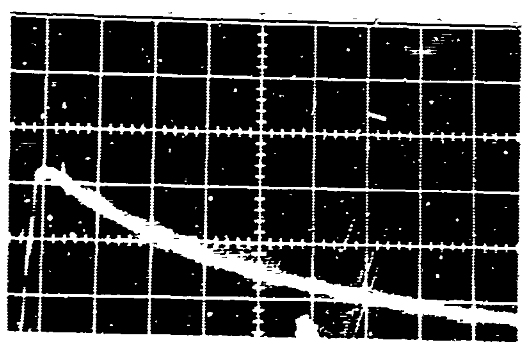
VERT SENS
350 psi/DIV
SWEEP SPEED
5 ms/DIV

90 mg BARIUM
STYPHNATE
LOADING PRESSURE:
10,000 psi



VERT SENS
750 psi/DIV
SWEEP SPEED
5 ms/DIV

90 mg BARIUM
STYPHNATE
LOADING PRESSURE:
15,000 psi



VERT SENS
750 psi/DIV
SWEEP SPEED
5 ms/DIV

FIG. 9 PRESSURE-TIME RESPONSES OF BARIUM STYPHNATE AT DIFFERENT LOADING PRESSURES

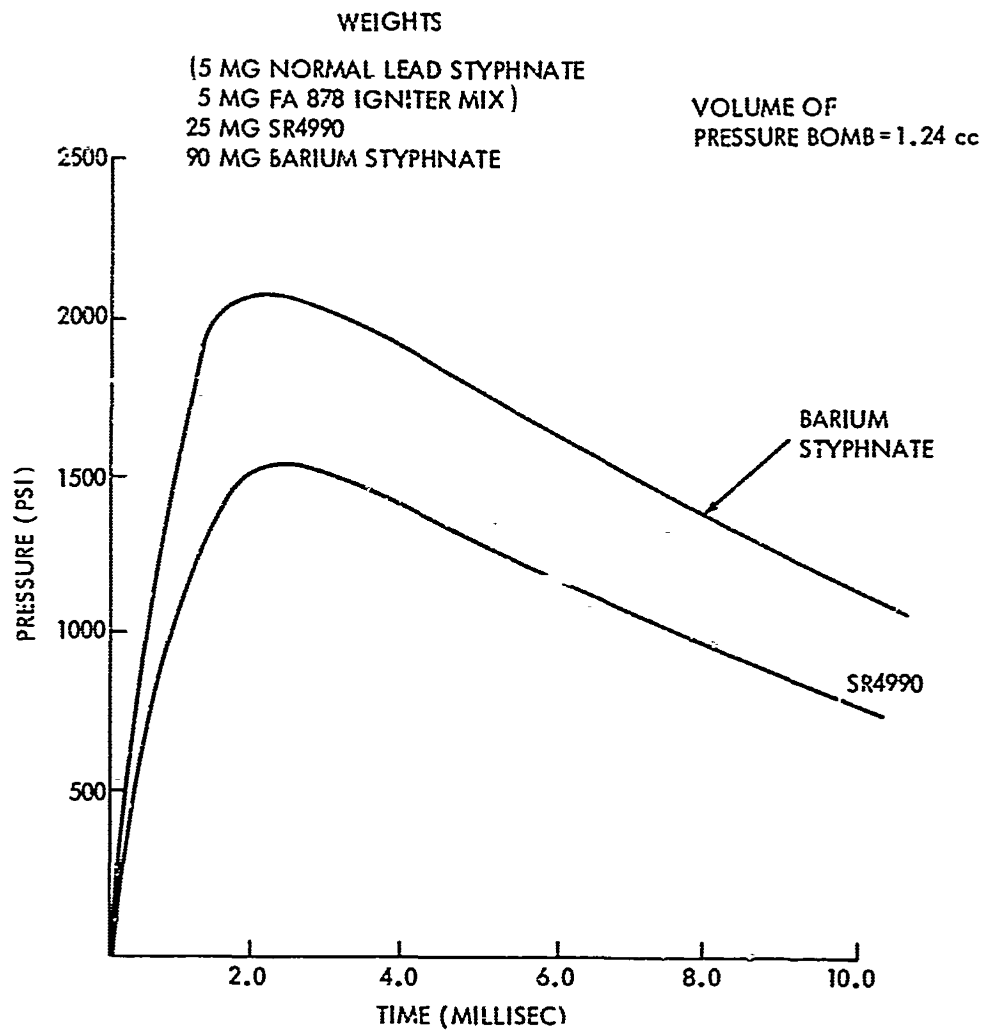
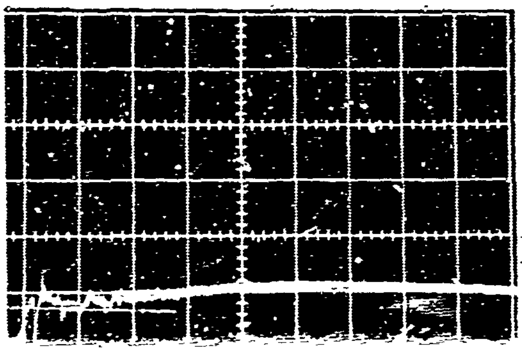


FIG. 10 PRESSURE-TIME RESPONSES OF SR4990 AND BARIUM STYPHNATE

15 mg LMNR

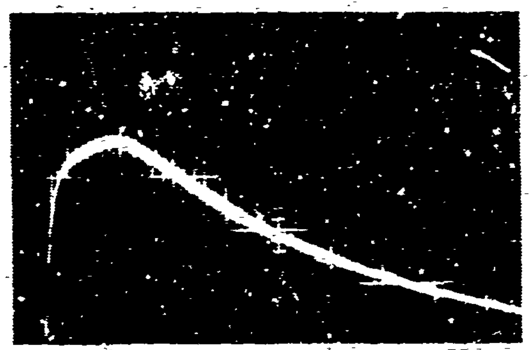


VERT. SENS.
250 psi/DIV.

SWEEP SPEED:
0.5 msec/DIV.

180 mg LMNR

LOADING PRESSURE
5,000 psi

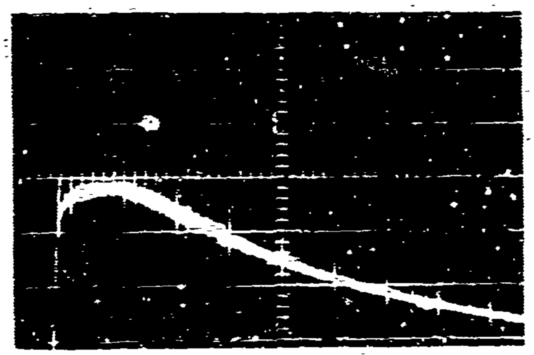


VERT. SENS.
250 psi/DIV.

SWEEP SPEED:
5 msec/DIV.

120 mg LMNR

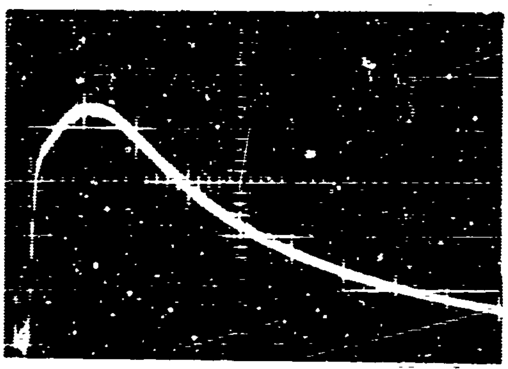
LOADING PRESSURE
10,000psi



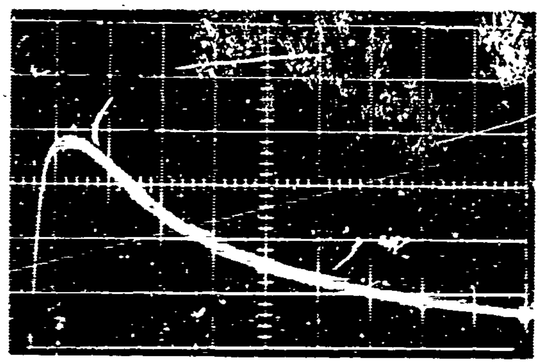
VERT. SENS.
200 psi/DIV.

SWEEP SPEED
5 msec/DIV

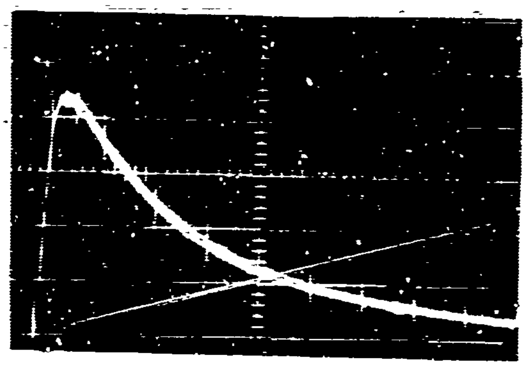
FIG. 11. PRESURE-TIME RESPONSES OF LMNR



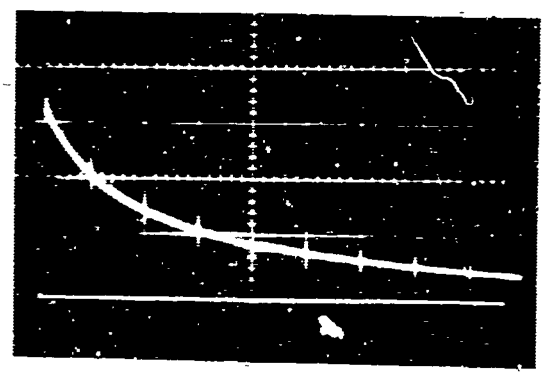
180 MG LMNR-$KClO_4$ (85/15)
VERT. SENSITIVITY: 460psi/DIVISION
SWEEP SPEED: 5 MSEC/DIVISION



180 MG LMNR-$KClO_4$ (80/20)
VERT. SENSITIVITY: 460psi/DIVISION
SWEEP SPEED: 5 MSEC/DIVISION



180 MG LMNR-$KClO_4$ (75/25)
VERT. SENSITIVITY: 460psi/DIVISION
SWEEP SPEED: 5 MSEC/DIVISION



180 MG LMNR-$KClO_4$ (60/40)
VERT. SENSITIVITY: 600psi/DIVISION
SWEEP SPEED: 5 MSEC/DIVISION

FIG. 12 PRESSURE-TIME RESPONSES OF DIFFERENT LMNR-$KClO_4$ MIXTURES

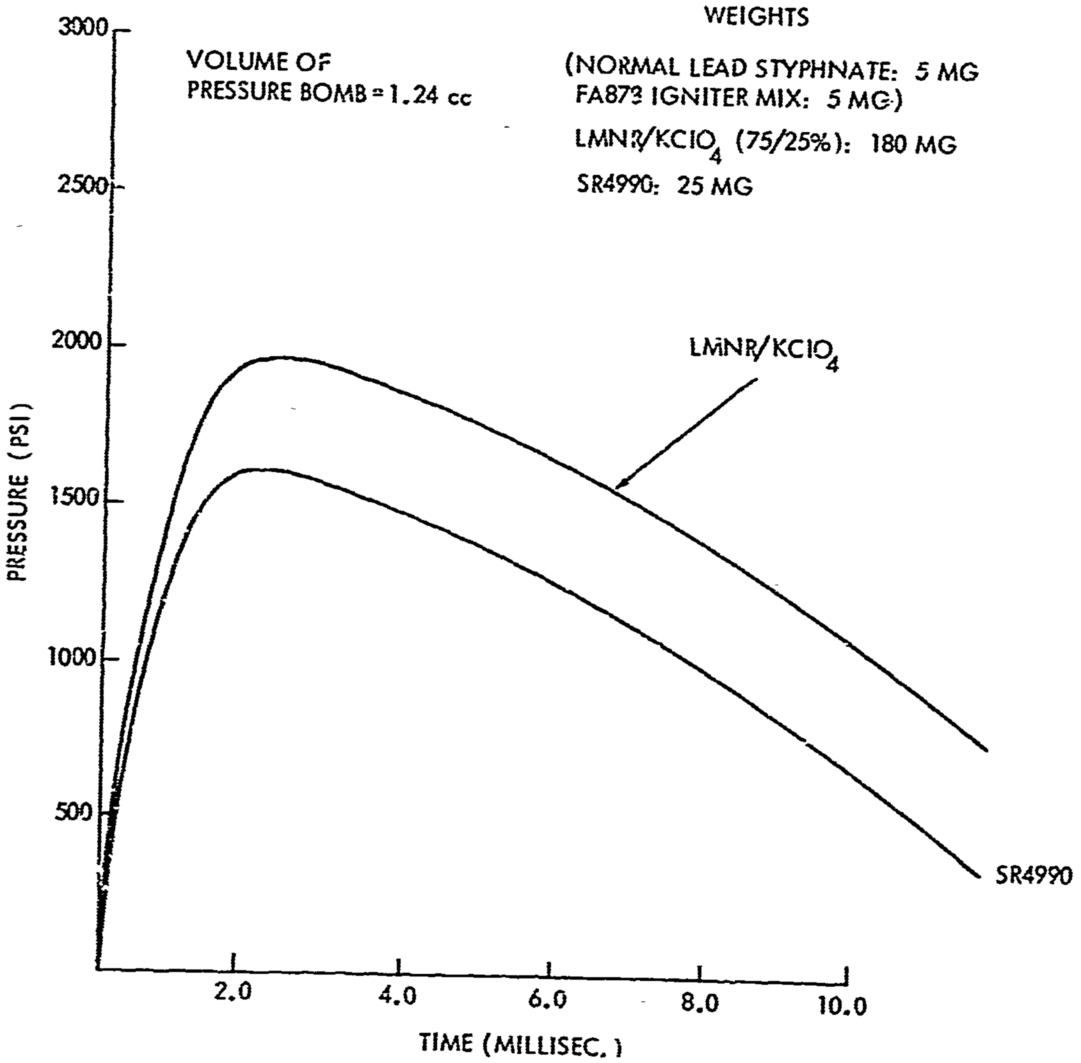


FIG. 13 PRESSURE-TIME RESPONSES OF LMNR/KClO$_4$ AND SR4990

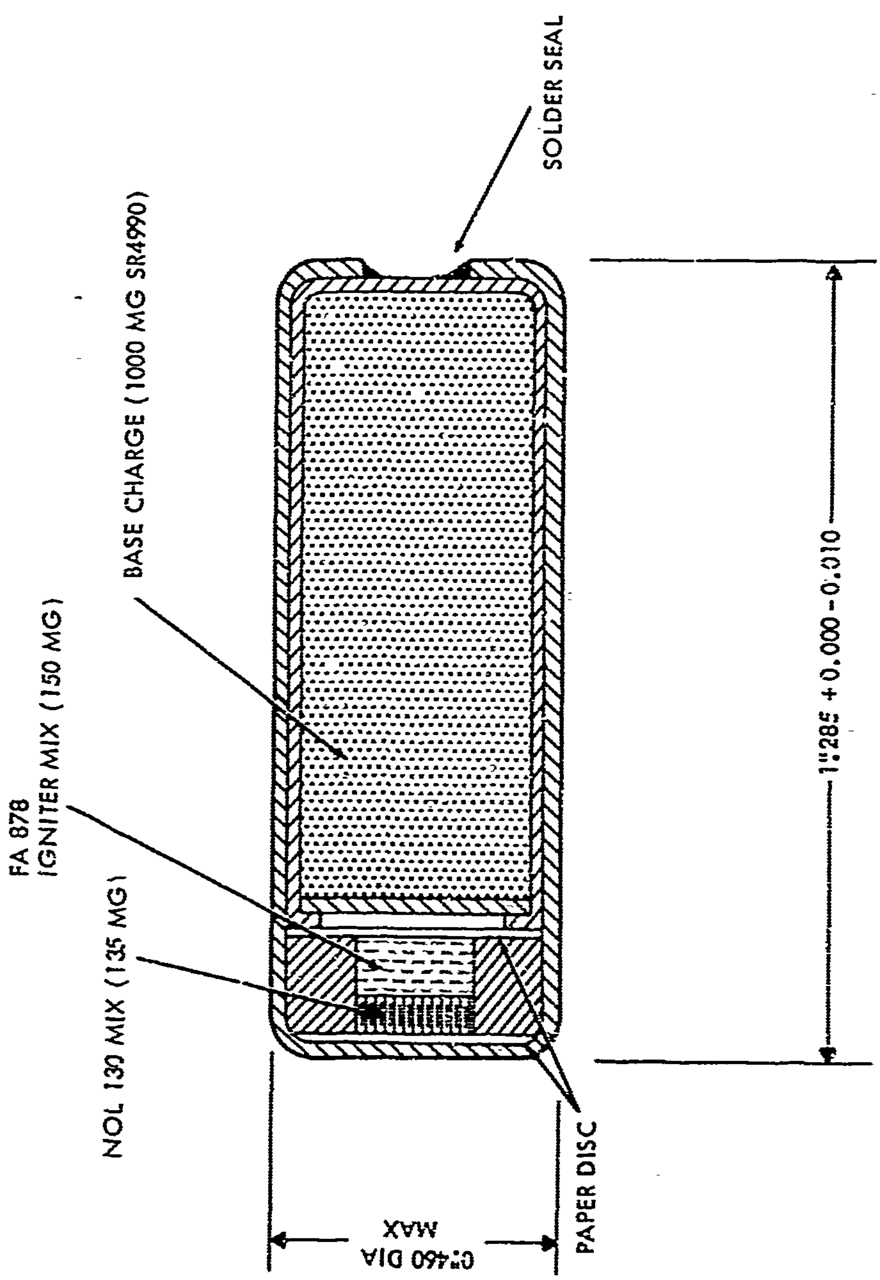
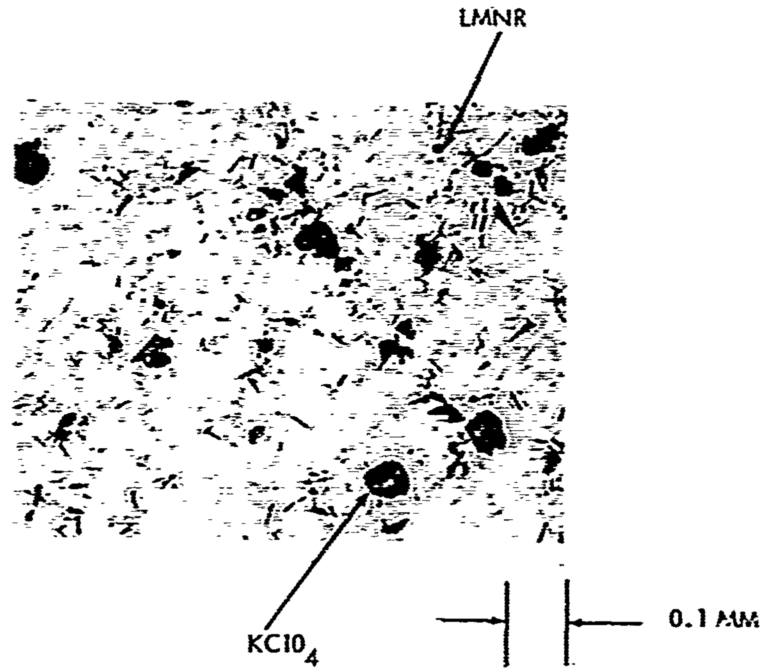


FIG. 14 MK 24 ACTUATOR



REMARKS: NOTE THE RELATIVE SIZES OF THE DIFFERENT CRYSTALS. PARTICLE SIZES OF INDIVIDUAL CONSTITUENTS ARE LESS THAN 75 MICRONS.

FIG. 15 PHOTOMICROGRAPH OF LMNR/$KClO_4$ MIXTURE

0.1 mm

REMARKS: NOTE THE WELL-FORMED CRYSTALS CONTAINING OCCLUDED MATERIALS, PROBABLY MOTHER LIQUOR. THE DARK CRYSTALS OCCUR BECAUSE OF THEIR ORIENTATION ON THE POLARIZING MICROSCOPE. PARTICLE SIZE RANGE IS FROM 10 TO 500 MICRONS.

FIG. 16 PHOTOMICROGRAPH OF BARIUM STYPHNATE

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13. ABSTRACT

~~DuPont~~ SR-4990, a single-base propellant used in Navy explosive actuators, is no longer produced. This necessitated a search for an adequate replacement for the SR-4990 in the Mk 24 Actuator. Experimental work was performed with barium styphnate, lead mononitroresorcinate, and two ~~DuPont~~ manufactured powders. Candidate materials were first screened using a pressure bomb. Final testing was performed in the Mk 24 Actuator design. Test results showed that of the four candidates, barium styphnate is the best material for the Actuator Mk 24.

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